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SKINFOLD MEASUREMENTS AS AN ESTIMATE OF SPECIFIC GRAVITY AND OF THE PERCENTAGE OF BODY FAT

BY

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "SKINFOLD MEASUREMENTS AS AN ESTIMATE OF SPECIFIC GRAVITY AND OF THE PERCENTAGE OF BODY FAT" submitted by MARILYN JOYCE BOOTH in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The accuracy of the skinfold regression formulae for predicting the specific gravity of the human body was tested. The formulae developed by Young et al (70) were applied to data obtained from a group of physical education students. At the 0.05 level of significance, these formulae, based on data obtained from normal young women, did not provide an accurate estimate of the specific gravity of the physical education students.

New regression equations were developed in an attempt to provide a more accurate estimate of the specific gravity of the physical education students. Eighteen such formulae were obtained. When both the predictive power of the equation and the accessibility of the sites were considered, the weighted combination of the triceps, umbilical, patella, and waist skinfold measurements was the most effective.

The specific gravity estimate, obtained by the hydrostatic weighing was used in three formulae, which had been developed by previous researchers, to estimate the percentage body fat. At the 0.05 level of significance, the three formulae yielded estimates of the percentage body fat which were significantly different from one another.

The relative thicknesses of the skinfold measurements obtained from corresponding sites on the right and left sides of the body were examined. With the exception of the triceps and xyphoid sites, no significant difference was found.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

With the higher standard of living and the increased availability of food, overnutrition and its effect upon the health of the individual have become a problem. In order to study the problem of obesity, researchers have been searching for a technique which will accurately estimate the percentage of the body weight which is fat (4,5,9,11,12,14,15,17,30,37,38,39,47,48,54,56,58,62,69).

Since the density of fat is low compared to other tissues, changes in fat content alter the specific gravity of the body (4,5, 11,17). From these changes in specific gravity, researchers have developed formulae which estimate the percentage of body weight which is fat.

The technique which provides the most accurate estimate of specific gravity (7,12,20,69,70), and one of the few methods which does not require hospitalization of the subject, is hydrostatic weighing. This prediction of specific gravity is based upon Archimedes' principle and involves weighing the individual underwater.

The hydrostatic weighing technique, however, has several shortcomings. The equipment required for the underwater weighing is

extensive and costly (70), the method for determining the weight underwater is relatively slow, and the subjects must be semi-trained and co-operative in order for the investigator to obtain an accurate measurement (20,70).

It would therefore, be useful to develop a technique which would provide an accurate estimate of specific gravity, be relatively practicable, and which would overcome the expense and administrative problems of hydrostatic weighing. Young states (72:905):

> None of the indirect methods of measuring total body fat in the living human is entirely practical for use in evaluating fatness of large population samples. ...Hence, to accumulate data on overnutrition in any sizeable representative sampling of the population, some simpler anthropometric method of evaluating overnutrition was needed. Since a large proportion of adipose tissue is located under the skin, measurement of subcutaneous fat has appeared to be the simplest criterion of relative fatness, particularily if subcutaneous fat could be related to and used as an index of total body fatness.

Several studies have investigated the use of skinfold calipers to measure body fat, and have developed regression formulae which give an estimate of the specific gravity (12,15,30,47,52,56,57,62,63, 70). Although many of these investigators have worked with males, a few have used female subjects and have considered the prediction of specific gravity from skinfold measurements (30,47,56,62,70). These studies, however, were not consistent with regard to the sites used, the side of the body measured, or the ages of the groups examined. Due to the inconsistency of previous work, generalization regarding

the value of skinfold measurements as an estimate of body fat is difficult. To obtain precise information, well-defined tests must be made upon all the various subgroups of the population. Newman states (53:43):

> No single survey will be adequate in this field, even within one population, because age (Brozek '52), sex (Skerlj, Brozek, and Hunt '53), and physical activity differences (Brozek '54), will require subsampling beyond the capacity of most surveys.

Since physical activity alters the fat to muscle ratio of the body (5,12,13,49), the specific gravity of active young women would be expected to be greater than the specific gravity of non-active young women.

In the present study, skinfold measurements were obtained from a group of young women similar in age to the subjects used by Young et al (70) in developing regression equations for predicting specific gravity. The subjects of this study, however, were considered to be more physically active. Thus, if the regression formulae developed by Young et al (70) will accurately predict specific gravity in this study, the scope of the formulae will be extended.

Problem

It was the purpose of this study:

1. To compare the estimates of the specific gravity obtained using the regression formulae developed by Young et al (70) with the estimates of specific gravity obtained using the hydrostatic weighing technique.

2. To analyse the skinfold measurement observed from the various sites and so determine the combination of sites which gives the best regression estimate of specific gravity. The criterion used for specific gravity was that value calculated from the hydrostatic weighing.

3. To substitute the specific gravity value, obtained from this study, into three formulae that have been developed to estimate the percentage of body fat. The three formulae used were those derived by Rathbun and Pace, 1945 (58), Keys and Brozek, 1953 (13) and Brozek et al, 1963 (17).

Subsidiary Problem

To add further to the knowledge and value of skinfold measurements, comparisons were made between:

1. The thicknesses of the skinfolds measured on the right-hand side of the body and on the left-hand side of the body.

Hypothesis

The following null hypotheses were tested for significance at the 0.05 level of probability.

1. There is no significant difference between the estimate of specific gravity calculated from the hydrostatic weighing technique, and the estimate of specific gravity calculated from the skinfold regression formulae developed by Young (70).

2. There is no significant difference between the estimate of

specific gravity calculated from the hydrostatic weighing method, and the estimate of specific gravity calculated from the skinfold regression equations developed from the sample data.

3. There is no significant difference between the thicknesses of the skinfolds measured on the right-hand side of the body, and the thicknesses of those measured on the left-hand side of the body.

Justification for the Study

Physical educators are concerned with the optimal health and efficiency of individuals. With a simplified, accurate method of estimating body fatness, further study of the relationship of obesity to health and efficiency could be conducted more easily.

Limitations

General Limitations

1. There is no method for direct measurement of the specific gravity of the living human body. All the techniques available provide only an estimate.

2. The constants used in the calculation of body fat from specific gravity have been derived from studies on males. These may not be applicable to females; indeed the proportionate composition of the female body is unknown.

3. There is no consideration given to individual differences in the proportions of the different body components when constants are used.

Limitations Specific to this Study

1. The temperature and humidity within the laboratory were not controlled.

2. The residual volumes of the subjects were not measured directly, but were estimated from the vital capacity.

3. The water was not maintained at exactly the same temperature, but the temperature was recorded for each subject, and was found to vary only a few degrees.

4. A Harpenden skinfold caliper was used in this study. This limited the comparability of the results with those of Young's investigation (70) in which a Lange caliper was used.

Delimitations

1. The study was confined to a randomly selected sample of twenty-four first-year physical education students at the University of Alberta during the 1967-68 academic year.

2. The estimates of specific gravity were limited to those obtained by the hydrostatic weighing and the skinfold methods.

3. Only formulae developed by Young and formulae developed from the sample data were used to estimate specific gravity from skinfold measurements.

Definition of Terms

1. Hydrostatic weighing is the method of estimating the specific gravity of a body by the use of the underwater weighing apparatus. The calculations are based on the formula:

$$D_b = \frac{M_a}{\frac{M_a - M_w}{D_w}}$$

where D_b = density of the body

M_a = weight of the subject in air

M_w = apparent weight of the subject in water

D_w = density of the water at that temperature.

2. Density is the mass of the body per unit volume.

3. Specific gravity is the ratio of the density of the substance to the density of water at 4°C.

4. Percent body fat is the percent of the body weight expressed as fat, estimated from the formula(58):

$$\%F = 100 \left(\frac{5.548}{\text{Sp.gr.}} - 5.044\right)$$

where F = body fat expressed as a percentage of body weight

Sp.gr. = the specific gravity of the body.

5. Subcutaneous fat is the layer of fatty tissue beneath the skin.

6. Skinfold is the thickness of a double layer of skin plus subcutaneous fat, as measured by a Harpenden skinfold caliper.

CHAPTER II

REVIEW OF THE LITERATURE

Body Compartments

Several studies (2,4,7,17,18,49,51,58) have discussed the problem of estimating the *in vivo* composition of the human body. Some have suggested formulae for predicting the body fat content; others have pointed out the shortcomings of the existing formulae. While many of these studies (4,7,51) agree that fat is the component of the body which causes the greatest variation in the body density, several studies (2,7,51) have indicated that the percentages of bone and other fat-free components are not constant for all individuals.

From the knowledge of the fat content of guinea pigs, and assuming the specific gravity of human fat and fat-free components to be 0.918 and 1.100 respectively, Rathbun and Pace (58) proposed the following formula for the prediction of percent body fat:

$$\%\ \text{Fat} = 100\ \left(\frac{5.548}{\text{specific gravity}} - 5.044\right)$$

Keys and Brozek (49) extended the work of Rathbun and Pace. From the chemical analysis of human cadavers, and from density changes following weight gain due to overeating, the densities of fat and fat-free

components were calculated to be 0.9007 and 1.102. The proportions and densities of all the components were combined to form the "Minnesota Reference Man" with a density of 1.0629 and with 14 percent of the body weight as fat. The formula for estimating body fat was revised to:

$$\% \text{ Fat} = 100\left(\frac{4.201}{\text{Density}} - 3.813\right)$$

Further study by Brozek et al (17) resulted in the development of a "Reference Body" to replace the "Reference Man". The "Reference Body" was based on knowledge of the density of fat, and of the changes in body density following weight loss as well as weight gain. The revised formula estimated the percentage of fat in the "Reference Body" to be 15.3, the body having a density of 1.064. The new formula was:

$$\% \text{ Fat} = 100\left(\frac{4.570}{\text{Density}} - 4.142\right)$$

Several studies (17,18,62) have compared the results obtained from the various formulae, and have found that the estimates are consistently different from one another.

Unfortunately, all of the available formulae have been based entirely upon data from male subjects so the validity of their application to females is questionable (19,30). The fact that women have a much greater proportion of their body weight as fat (cited 18, 44) suggests that the body compartments differ from those of the

male (30).

The accuracy of the prediction of total body fat from anthropometric data is limited by the assumptions underlying the numerical constants in the formulae (18,51,52,68). These assumptions have been summarized by Wartenweiler, Tanner, and Watanabe (68):

1. That the separate densities of the body components are additive.
2. That the densities of the constituents of the body are relatively constant from person to person.
3. That an individual differs from the "standard reference man" only in the amount of adipose tissue he possesses.

Thus, any study which involves an estimation of the percentage of body fat is dependent upon the correctness of a number of assumptions. Assessment of specific gravity itself, however, is not affected by the errors inherent in these assumptions and so can be measured with a greater degree of certainty.

Hydrostatic Weighing Technique

Hydrostatic weighing, based on Archimedes' principle, is a method for estimating the density of a body by weighing under water (4,7,20,40,51,68,69,70). A high degree of reliability has been reported following retesting of the same subjects (29,43,46,cited 49).

Durnin and Taylor (29) reported that an error of $\pm$ 0.004 units could be expected in ninety percent of cases, while Keys and Brozek (49) cited a study in which an error of $\pm$ 0.005 units in ninety percent of cases was expected. Katch, Michael, and Horvath (46)

recorded individual variations of 0.0004 to 0.0007 Kg. with the correlation coefficients between adjacent weighing reported to be 0.92 to 0.99. Howell, Moncrief, and Morford (43) reported a reliability of 0.87 at forced expiration and a reliability of 0.92 at forced inspiration.

Several other methods have been proposed which give an estimate of percent body fat or lean body mass. One method, the estimate of total body water, lacks reliability due to large variation from day to day (7,49). Another method, the creatine measure, still requires validation (11). The helium technique gives an estimate of body volume, but requires expensive equipment and a large number of trained technicians (20). For these reasons, the hydrostatic weighing technique has been considered superior (11,20,70).

Although the hydrostatic weighing technique has several shortcomings, modifications to the original method have attempted to overcome many of these. The hydrostatic technique is actually used to provide an estimate of body volume for the calculation of body density. Measurement of volume in this way requires that correction be made for the volumes of gas trapped in the lungs and gastrointestinal tract. It is the measurement of these volumes which poses the greatest problem when the weight underwater is recorded (6). Formerly, the subjects were instructed to exhale completely prior to the measurement (6,7,10,23,28,62,63,69,70), but there is some evidence that anxiety due to the lack of familiarity with the procedure inhibits the exhal-

ation prior to submersion (10,43). Howell, Moncrief, and Morford (43) reported a higher reliability when the subjects were measured after forced inhalation than after normal inhalation or forced exhalation. Similarly, Behnke, Feen, and Welham (4) reported that the difference between the hydrostatic weights obtained at maximum inhalation and at maximum exhalation could be corrected by subtracting the volume of the vital capacity. It has been recommended that the measurement of lung volume be made while the subject is partially submerged (6,10) as the vital capacity decreases significantly under these circumstances (23). The residual volume is similarily dependent, although the difference does not reach significance (10,23).

Aside from the lung volume, correction must be made for the volume of gas in the gastrointestinal tract. This volume has been estimated as 115 ml. at BTPS in normal individuals (3,20,51).

As well as limiting the anxiety of the subject by weighing him after maximal inhalation, fear may be decreased further by permitting the subject to sit partially submerged, and then to submerge himself fully, merely by bending forward (40). As well as increasing the subjects' body control, this method lessens the disturbance to the water, thus aiding in a more accurate and more rapid weighing (40).

Any lack of cooperation may thus be partially overcome, but little can be done to decrease the amount of time required to obtain the underwater weight (20).

Skinfold Caliper Technique

The main advantage of the skinfold caliper technique for estimating body fatness is the speed and simplicity with which the measurements can be obtained (11,25,66,71,72). Aside from its simplicity, the skinfold technique is fairly accurate, having been rated inferior only to the hydrostatic weighing technique as an accurate index of the density of the body (12,25,71,72). The use of skinfold estimates is based on the idea that the level of subcutaneous fat is indicative of the total fat content of the body (1,37,49,53).

Although one study (23) has stated that skinfold thicknesses should be measured in the morning to avoid variation due to dehydration, other studies (8,37) have found no variation with time of day and change in the hydration level. Conversely, a high reliability has been reported (8, cited 49,54). As a further validation, other studies have used other techniques to measure subcutaneous fat thickness (9, 15,38,39,63,67,72) and reported a high correlation with the skinfold caliper measure. These criterion measures - ultrasound, Roentgenograms, and conductivity - have not replaced the skinfold caliper technique due to the limited areas accessible for measurement, the need for expensive equipment and highly trained technicians, the exposure to X-radiation, and the discomfort to the subject (11,49,63,72).

The effectiveness of the skinfold measurements is dependent, to some extent, on the sites measured. While the number and location of the sites is, in part, determined by the objectives of the study (16), several other factors should be considered (14,16,32):

1. The accessibility.

2. The precision with which the site may be located on different individuals.

3. The homogeneity of the skin and the subcutaneous fat in that area.

4. The validity of the skinfold thickness at that site as an index of total body fat.

5. The ease with which the fold can be lifted from the underlying fascia.

One limitation of the technique may be the slight variation in fold thickness on opposite sides of the body. Several studies (8, 27,37) have noted differences between the right and left sides of the body, but most of these differences have been localized to one or two sites and have been reported small enough to be disregarded (27).

A knowledge of the age changes that occur in the patterns of the subcutaneous fat is important in the choice of skinfold sites. The largest change in fat patterning occurs in girls of about 14 years (55). Near this age, there is an increase in the fat deposits on the back, and upper chest (56) as well as increases on the lateral aspects of the trunk and the legs (33). Measurements in young women have indicated that the fat deposition in the abdominal region gives the best estimate of body fat (70). With further aging, there is a trend toward an increase in the trunk deposition of fat, and a limitation of the fat content in the extremities (61). At the same time the sub-

cutaneous fat layer tends to decrease in thickness from the proximal to the distal areas (32). In most women, the greatest deposition occurs around the shoulders, the base of the neck, and back, the abdomen and the proximal portions of the extremities (32).

Estimates of Body Density from Skinfold Thickness

In an attempt to estimate the body density, specific gravity, or fat content from the thickness of the subcutaneous fat layer, researchers have reported various combinations of skinfold measurements which they used to predict the desired variable.

Parizkova (56) found a high correlation between the subscapular skinfold and density for girls 13 to 16 years of age. High correlation coefficients were also obtained for density and the anterior axillary skinfold, as well as for density and the abdominal skinfold. Regression equations were developed from each skinfold measure separately and from several combinations of skinfolds. The best multiple correlation coefficient was recorded from a combination of the logarithmic values of the triceps and subscapular skinfold measures.

Seltzer (60), testing obese girls, found a high correlation between body density and the triceps skinfold measurements. By using the regression equation for that site developed by Parizkova (56), a very close estimate of density was obtained.

Durnin and Rahaman (21) developed a regression equation to estimate the body density of young women from the logarithmic value of the sum of four skinfold thicknesses. Katch and Michael (47) were

able to estimate density using the triceps skinfold, while Sloan, Burt, and Blyth (62) found the best predictors to be a combination of the iliac and triceps skinfolds. Young et al (70) recorded an accurate estimate of specific gravity from a combination of the pubic skinfold and the standard weight.

There does not appear to be any record of a study in which the equations of Durnin and Rahaman (21), of Katch and Michael (47), or of Sloan, Burt, and Blyth (62) have been applied to a similar group of young women. Steinkamp et al (65) tested a number of anthropometric equations on a group of young women; Young's regression equation (70) produced a significant multiple correlation coefficient of $R = 0.680$.

While these studies suggest that the skinfold regression equations are able to predict body density of a similar group of subjects, the full range of application of the equations has not been examined.

CHAPTER III

METHODS AND PROCEDURES

Subjects

The accuracy of the skinfold caliper technique for estimating the specific gravity of the human body was studied on twenty-four first year female university students. The subjects were randomly selected from the 1967-68 freshman class in the physical education and recreation programme at the University of Alberta.

Introduction

The specific gravity of each subject was estimated from the hydrostatic weighing technique. Skinfolds were measured at twenty-five sites. Using the regression formulae developed by Young (70), the specific gravity was estimated from the skinfold thicknesses. The two estimates of specific gravity were then compared.

From the skinfold measurements which correlated well with specific gravity, regression formulae were calculated. The formulae were developed using one to eleven skinfold measurements in various combinations. The criterion of specific gravity was the estimate from hydrostatic weighing.

The estimates of specific gravity which were calculated from the formulae were compared to the specific gravity estimate obtained

by hydrostatic weighing. The predictive power of each formula was calculated from the results.

The Hydrostatic Weighing

A cylindrical tank constructed of sixteen guage galvanized steel plate was used for the underwater weighing. The tank was six feet deep and four feet in diameter.

The temperature of the water entering the tank was controlled by a Powers Hydroguard thermostatic inlet.

Stainless steel cables were used to suspend an aluminum chair in the centre of the tank. The cables were connected to a strain guage suspended from the ceiling. A Sargent recorder was used to amplify and record the force acting upon the load cell of the strain guage.

Since the weight underwater was recorded during maximal inhalation, a twenty pound weight, with an underwater weight of seventeen and one half pounds, was used to prevent flotation of the subject.

Procedure

The subject, dressed in a nylon bathing suit and not wearing a bathing cap, was weighed in air.

The subject entered the tank, and sat in the chair with the water reaching neck level.

The vital capacity of the subject was measured in this position,

using a Collins wet spirometer. The largest volume of three trials was assumed to be the best estimate of vital capacity.

The subject dislodged any air bubbles that had collected from the water and that were trapped in her hair.

The subject placed the weight on her thighs.

The subject inhaled maximally, closed the nasal passage by holding her nose, and lowering her head below the surface of the water.

The tester obtained the reading on the recorder, and instructed the subject to lift her head.

Since a larger inhalation would cause a lower reading, the lowest of three readings was recorded.

The water temperature, room temperature, and barometric pressure were recorded.

Calculation of Specific Gravity

The density of a body is the mass per unit volume. Thus, the formula for calculating density is:

$$D = \frac{M}{V}$$

where D = density

M = mass or weight in air

V = volume of a body.

According to Archimedes' Principle, a body is buoyed up by

a force equal to the weight of the water displaced. The volume, therefore, is:

$$V = \frac{M_a - M_w}{D_w}$$

where V = volume of the body

M_a = weight of the body in air

M_w = apparent weight of the body in water

D_w = relative density of the water.

The total volume of gas was calculated as the sum of the vital capacity, the residual volume, and the gastrointestinal gas.

$$TVG = VC + RV + Gl$$

where TVG = total volume of gas

VC = vital capacity

RV = residual volume estimated as twenty-five percent of vital capacity (22)

Gl = gastrointestinal gas, assumed to be 0.115 litres at BTPS (3,20,51).

Total lung volume was multiplied by 61 in order to convert it to cubic inches.

The density of the body is:

$$D = \frac{M_a}{M_a - M_w - 0.0362(TVG)} \times D_w$$

where 0.0362 = the weight supported by one cubic inch of air at BTPS.

The specific gravity is the density of a substance compared to the density of water. Thus, the specific gravity is

$$Sp.Gr = D_b \div D_w$$

where D_b = the density of the body

D_w = the density of the water.

The Skinfold Technique

The skinfold thicknesses were measured using a Harpenden skinfold caliper.

The caliper was calibrated to exert a constant pressure of ten grams per square millimetre of jaw surface, regardless of the thickness of the skinfold. The total pressure of the jaw faces was 880 grams.

The dial of the caliper was subdivided to 0.2 millimeters, but could be interpolated to read to 0.1 millimetres.

Procedure

The skinfold sites were located and marked.

The skin was lifted by grasping the fold between the thumb and forefinger of the left hand. The fold included a double layer of skin and subcutaneous fat, but no muscle or fascia.

The calipers were applied about one centimetre from the fingers, and at a depth approximately equal to the thickness of the skinfold. The grasp of the thumb and finger was released.

The sequence of readings was repeated three times. The mean of the three values was calculated and was used in the analysis.

Skinfold Sites

The sites were the same as those used by Young (69,70).

The following sites were used:

The chin site was located halfway between the tip of the mandible and the hyoid bone.

The triceps skinfold was lifted halfway between the acromion process and the tip of the olecranon process, on the dorsal surface of the arm. It was measured while the arm was relaxed by the side.

The subscapular site was measured at the tip of the scapula. The fold was lifted at a forty-five degree angle, medially upward.

The pectoralis site was located along the border of the pectoralis major muscle, superior to the axilla. The subject placed her hand on her hip while the fold was measured.

The xyphoid site was lifted level with the xyphoid process, on the mid axiallary line.

The lower rib site was located halfway between the axilla

and the iliac crest.

The waist site was measured halfway between the lowest rib and the iliac crest, on the midaxillary line.

The suprailiac site was located medial to the anterior superior iliac spine. The fold was lifted at a forty-five degree angle, laterally upward. The subject was in a supine position, with her feet flat on the bench, and her knees flexed.

The umbilical skinfold was lifted one and one half inches lateral to the umbilicus. The subject was in a supine position.

The abdominal site was located halfway between the umbilicus and the symphysis pubis, one and one half inches lateral to the mid-line of the body. The subject was in a supine position.

The front thigh site was halfway down the front of the thigh, over the quadriceps femoris muscle. The subject was supporting her weight on her opposite leg.

The patella site was directly over the patella.

The knee site was above the patella (12).

The subject was standing while the skinfolds were measured, except for the suprailiac, abdominal, and umbilical readings. In the case of these three sites, the supine position with the knees flexed was used to facilitate relaxation of the abdominal muscles.

Unless otherwise specified, the skinfolds were lifted parallel to the long axis of the body.

The sites, except the chin site, were duplicated on the right

and left-hand sides of the body.

Statistical Analysis

The means and standard deviations were calculated for all variables.

A correlated t test was used at each skinfold site to test the difference between those measured on the right and left-hand sides of the body.

A one-way analysis of variance was used to test the differences between estimates of specific gravity obtained by hydrostatic weighing and skinfold regression equations. Dunnett's multiple comparison was used to determine which regression estimates differed from the estimate obtained from hydrostatic weighing.

All tests were made at the 0.05 level of significance.

CHAPTER IV

RESULTS AND DISCUSSION

Characteristics of the Subjects

Twenty-four healthy female subjects, randomly selected from the first year undergraduate students enrolled in the Faculty of Physical Education at the University of Alberta, participated in the study. The age, height, and weight of these subjects are reported in Table I.

Table I

Age, height, and weight of subjects

Variable	Mean	Standard Deviation	Range
Age (yr.)	18.67	0.63	17.92 - 20.42
Weight (Kg.)	59.24	5.87	48.75 - 68.41
Height (in.)	65.28	2.10	60.50 - 68.50

The subjects of the present study are older than those studied by Parizkova (56), and are slightly younger than those studied by Young et al (70), Sloan, Burt, and Blyth (62), Durnin and Rahaman (30), and Katch and Michael (47).

The mean body weight in the present study was 59.24 $\pm$ 5.87

kilograms. This is similar to the mean weights of 58.96 $\pm$ 6.445 kilograms reported by Young et al (70), 55.9 $\pm$ 9.2 recorded by Durnin and Rahaman (30), 58.38 $\pm$ 6.7 measured by Katch and Michael (47), and 55.5 $\pm$ 5.9 reported by Sloan, Burt, and Blyth (62). The subjects of the present study, whether because of age or fitness level, have slightly heavier body weights. A number of other studies (5, cited 12,13,45,48) have reported an increase in body weight and a decrease in body fat in physically active subjects.

Skinfold Thicknesses

The mean, standard deviation, and range of the skinfold thicknesses are recorded in Table II. When the differences between the right and left sides of the body were tested, the right tricep fold was significantly larger than the left, the left xyphoid was significantly larger than the right, and the sum of the right skinfold thicknesses was significantly larger than the sum of the left at the 0.05 level of significance. No other sites differed significantly.

Damon (27) reported a significantly larger right tricep skinfold thickness for male subjects. Fletcher (37), on the other hand, noted that the skinfolds on the left side of the female subjects were larger than those on the right, while Booth (8) found a significantly larger right pectoralis and right waist skinfold thicknesses on a group of female university graduate students. Since there appears to be no definite trend of differences between the right and the left sides of the body, the measurements on the right were used in this

TABLE II

Skinfold thicknesses (millimetres). R denotes the measurement on the right side of the body, L on the left side

Site	Mean	Standard Deviation	Range
Chin	7.06	± 1.59	3.8 - 11.6
R tricep	15.39*	± 4.15	6.8 - 23.3
L tricep	13.92	± 3.45	5.4 - 20.8
R subscapular	10.72	± 2.99	5.2 - 17.3
L subscapular	10.58	± 2.90	5.4 - 16.8
R pectoralis	3.85	± 1.85	0.3 - 10.4
L pectoralis	4.03	± 1.73	0.3 - 10.0
R xyphoid	7.30*	± 2.26	3.6 - 14.2
L xyphoid	7.64	± 2.56	3.3 - 14.5
R rib	9.27	± 3.56	3.7 - 19.1
L rib	9.25	± 3.54	3.6 - 16.8
R waist	11.68	± 4.51	4.2 - 21.0
L waist	11.69	± 4.79	4.1 - 20.9
R iliac	9.28	± 3.13	3.4 - 16.0
L iliac	9.03	± 3.30	3.1 - 16.5
R patella	7.88	± 2.96	3.7 - 17.0
L patella	7.46	± 2.68	3.8 - 15.6
R umbilical	9.39	± 3.43	4.0 - 17.9
L umbilical	9.02	± 3.20	4.2 - 19.0
R abdominal	15.41	± 6.05	3.7 - 31.9
L abdominal	15.04	± 5.90	3.9 - 32.3
R sum	100.17*	± 28.53	40.4 - 171.0
L sum	97.66	± 27.91	39.3 - 168.8

*Significantly different at the 0.05 level.

study for testing the regression formulae developed by Young et al (70), as well as for developing new prediction equations.

The thigh and the knee skinfold sites were not used in this study as difficulty was experienced in lifting these folds. With the exception of a few subjects, only very firm folds could be lifted. The calipers would not grip these firm folds, so no reading could be recorded. In a few cases, similar difficulty occurred at the tricep site, but enough evidence was obtained to predict the few missing values by the method outlined by Goulden (41).

When the present skinfold values were compared to those obtained by Young et al (69:336) in Table III, similar results were obtained for the chin, subscapular, xyphoid, lower rib, and waist sites. For the other sites, the thicknesses reported by Young et al (69) were much larger than those recorded in the present investigation. The four skinfold thicknesses recorded by Sloan, Burt, and Blyth (62) are closer, but still larger than the skinfolds in the present study. The four skinfolds measured by Katch and Michael (47) are similar to the corresponding sites in the present study. The deviation of the measures may be due, in part, to the larger age range studied by Young et al (69). The age range in the study by Young et al (69) was seventeen to twenty-seven years, Sloan, Burt, and Blyth (62) measured young women seventeen to twenty-five years of age, and Katch and Michael (47) measured subjects nineteen to twenty-three years of age, while the present study included only subjects seventeen to twenty.

TABLE III

A summary of skinfold thicknesses recorded

in a number of investigations

Sites (mm.)	Present Study	Young et al (69)	Sloan, Burt, Blyth (62)	Katch, Michael (47)
Chin	7.06	7.06		
Triceps	15.39	25.43	16.08	12.31
Subscapular	10.72	12.07		10.81
Pectoralis	3.85	6.64		
Xyphoid	7.30	8.67	10.84	
Lower Rib	9.27	10.46		
Waist	11.68	14.65		16.49
Iliac	9.28	20.74	19.16	
Patella	7.88	11.37		
Umbilical	9.39	22.93		15.19
Abdominal	15.41	33.04	19.40	

Another explanation of the variation could be the probable higher fitness level of the subjects in this study.

In this study, the largest skinfold thickness was the abdominal fold with a mean caliper reading of 15.41 mm. The second largest was the triceps skinfold with an average thickness of 15.39 millimetres. The waist and subscapular sites had the next largest skinfolds, while the pectoralis, chin, and xyphoid sites showed the lowest measures of subcutaneous fat. From the previous work, there is some evidence that the subjects in this study may be undergoing a transition in their fat patterning from the deposits on the back and upper chest found in teenage girls (56), to the deposition of a larger proportion of subcutaneous fat on the trunk in older groups (61).

Density, Specific Gravity, and Fat Content

The mean values for the density, specific gravity, and fat content are recorded in Table IV. The means of the density and the specific gravity in the present investigation were 1.0429 and 1.0475, respectively. These are slightly higher than the 1.0342 and 1.0408 recorded by Young et al (69). The mean density value obtained in the present study is similar to the mean density values reported in other studies - 1.0467 (62) and 1.049 (47). The density value is also comparable to that of 1.0442 reported for the intermediate body build group measured by Durnin and Rahaman (30).

The mean fat content for the subjects in the present group was 25.31 $\pm$ 5.43 percent when the formula of Rathbun and Pace (58) was used. This corresponds to 15 Kg. of fat. Young et al (70), using the

TABLE IV

Density, specific gravity, and fat content

Variable	Mean	Standard Deviation	Range
Density (gm/ml)	1.043	± .011	1.021 - 1.057
Specific gravity	1.048	± .011	1.026 - 1.062
Rathbun and Pace Formula (1945)			
% Fat	25.31	± 5.43	18.11 - 36.39
Kg Fat	15.01	± 3.49	8.99 - 23.57
Keys and Brozek Formula (1953)			
% Fat	21.55	± 4.12	16.30 - 30.20
Kg Fat	12.78	± 2.70	8,09 - 19.56
Brozek et al Formula (1963)			
% Fat	24.03	± 4.49	18.30 - 33.45
Kg Fat	14.25	± 2.95	9.09 - 21.67

same formula, calculated the body fat for a group of less active young women. Their mean value of 28.69 ± 4.856 percent indicates a larger fat content.

Using the formula developed by Brozek et al (17), Katch and Michael (47) reported the fat content of female subjects to be 21.5 ± 5.7 percent. The corresponding value for the present study was 24.0 ± 4.49 percent. Sloan, Burt, and Blyth (62) recorded a body fat content of 20.06 ± 4.63 percent using the formula of Keys and Brozek (49) and 22.13 ± 7.08 percent using the formula of Rathbun and Pace (58). The corresponding values in the present study were 21.55 ± 4.12 percent and 25.31 ± 5.43 percent.

Katch and Michael (47) collected the data from nine studies reported from various areas of the world and calculated the body fat using the formula of Brozek et al (17). The fat content of the young women in the present study was slightly greater than all but one of the studies reported by Katch and Michael. The exception was the investigation of Young et al (70). The fat content recorded in the study by Young et al was 3.8 percent larger than any other study reported. No explanation for this can be given without a more detailed knowledge of the groups. Katch and Michael suggested that the difference may be due to variation in climatic and seasonal conditions, as well as to genetic factors. They also suggested that the subjects from their study may have been more diet conscious than the subjects from other areas of the world. The subjects from other areas of the world may

also have participated in more physical activity than the normal groups in North America. If this were the case, diet and physical activity differences might possibly explain the limited fat content of the groups reported.

Percentage Body Fat Calculated by Different Formulae

When the results from the three formulae (17,49,58) for predicting percentage of body fat were compared, using a one-way analysis of variance, a significant difference between the estimates was found at the 0.05 level of significance. This confirms the findings of previous studies (17,18,62).

Specific Gravity Estimates from Skinfolds using the Regression Formulae Developed by Young et al (70)

The mean values of the estimates of specific gravity obtained from the regression formulae developed by Young et al (70) are reported in Table V. The coefficients of multiple correlation between the predicted values and the measured specific gravities were not significantly greater than zero at the 0.05 level of significance. The coefficients of multiple correlation, obtained by Young et al (70) when the regression formulae were derived, are also recorded to permit a comparison.

When a one-way analysis of variance was used, there was no significant difference, at the 0.05 level, between the predicted specific gravities and the measured value. At first, this seems hard to reconcile with the lack of correlation. The analysis of variance, however, is a

TABLE V

Estimates of specific gravity using
Young's regression formulae

Formula	Mean	Standard Deviation	Range	R*	Original R
Y2B	1.0617	.0022	1.0558 - 1.0650	.1674	.7218
Y3	1.0079	.0206	0.9511 - 1.0477	.3291	.6825
Y4	1.0594	.0015	1.0557 - 1.0626	.1581	.6746
Y5B	1.0596	.0015	1.0563 - 1.0631	.0667	.6737
Y6	1.0513	.0036	1.0415 - 1.0582	.3223	.6529

*R is the coefficient of multiple correlation obtained between the predicted and the criterion measure of specific gravity.

where:

Y2B includes the abdominal (pubic), lower rib, iliac, chin, pectoralis, and patella skinfold sites

Y3 includes the abdominal (pubic), lower rib, triceps, and iliac skinfold sites

Y4 includes the abdominal (pubic), lower rib, and triceps skinfold sites

Y5B includes the abdominal (pubic), and lower rib skinfold sites

Y6 includes the abdominal (pubic) skinfold site

test of the differences between two or more mean scores (31). In other words, the mean scores for the predicted specific gravities and the measured specific gravity could be similar without the existance of a correlation.

An examination of the predicted and measured specific gravity values for each individual (Appendix C) reveals that the predicted values are generally higher than those obtained by the hydrostatic weighing. Normally, a thick skinfold would indicate that a large proportion of the body weight is fat. Specific gravity, however, is inversely related to the body fat content so that a large percentage of body fat would correspond to a small specific gravity. The skinfold regression formulae developed by Young et al (70) were based on subjects who had a concentration of subcutaneous fat in the lower body so that some of the skinfold thicknesses reported (70) were almost twice the size of the corresponding skinfold measures recorded in the present investigation. The specific gravity values recorded by Young et al (70), from hydrostatic weighing, are not grossly different from those calculated in this study. Since very thick skinfolds were used initially to derive a formula which would predict a specific gravity similar to that found in the present investigation, the much thinner layer of lower body subcutaneous fat may account for the high specific gravity estimates obtained from the regression formula developed by Young et al (70).

Development of Regression Equations to Predict Specific Gravity

The coefficient for the correlation between the skinfolds from the individual sites, the sum of the skinfold thicknesses, and the specific gravity, are recorded in Table VI. The corresponding coefficients obtained by Young et al (70) are included to permit comparison. Young et al found that body density correlated most highly with the pubic (abdominal) skinfold, followed by the suprailiac, and lower rib skinfold sites. In the present study, specific gravity correlated most highly with the triceps, the umbilical, and the suprailiac skinfolds, in that order.

The regression equations were developed in a stepwise fashion. Measurements from all of the skinfold sites were used to derive the initial regression equation. Variables were then eliminated by successively dropping the skinfold measurement which contributed least to the predictive power of the equation. Each time a prediction was dropped, a new equation was formed, until there were only five variables remaining. All the possible combinations of these five predictors, taken four, three, and two at a time, were then used to formulate other regression equations. Finally, each site was used alone to obtain a regression equation for predicting the specific gravity. The coefficients of multiple correlation, between the measured specific gravity and the values predicted from each of the equations, were then calculated. All of these coefficients were tested for significance at the 0.05 level. Any regression equation which did not yield a significant

TABLE VI

Correlation coefficients between skinfold thicknesses, total skinfold measurements, and specific gravity

	Correlations obtained in the present study		Correlations obtained by Young	
Skinfold Site	Total Skinfold	Specific gravity	Total Skinfold	Density
Chin	.3852	-.3173	.6003	-.4839
Scapula	.5705	-.3134	.7667	-.5161
Xyphoid	.4793	-.3555	.8384	-.5615
Pectoralis	.5221	-.3933	.6580	-.3558
Lower rib	.5099	-.3413	.8883	-.6110
Waist	.3695	-.2545	.8824	-.6042
Umbilicus	.4153	-.4810	.8717	-.6049
Abdominal (Pubis)	.3493	-.3236	.9020	-.6590
Suprailiac	.5202	-.4156	.8681	-.6298
Tricep	.4400	-.4907	.8176	-.5210
Thigh	--	--	.7462	-.4853
Patella (Knee)	.5518	-.1834	.4994	-.3772

correlation coefficient was deleted from the study. The most significant correlation coefficient was produced by the seven-predictor combination. The other significant correlation coefficients were then tested for significance against the correlation coefficient from the seven-variable combination. Any regression equation which did not satisfy this criterion was also deleted from the study.

Those regression equations which remained were those which had produced coefficients of multiple correlation which were significantly different from zero, but not significantly different from the correlation coefficient produced by the best, seven-predictor, equation. These regression equations are listed in Table VII. The coefficient of multiple determination (R^2), which indicates the proportion of the variation in the measured specific gravity which can be predicted by the regression equation estimate, is listed for each regression equation. The means and the standard deviations for the predicted values of specific gravity obtained from each regression equation, as well as the multiple correlation coefficients, are listed in Table VIII.

The best estimate of specific gravity from the skinfold measurements was obtained when seven skinfold sites were used as predictors in equation 7a. The coefficient of multiple determination, however, was only 0.42. In other words, the best estimate of specific gravity accounted for only forty-two percent of the variation found in the hydrostatic weighing estimate of specific gravity. Deletion of the chin and the iliac skinfold sites produced a regression equation (5a)

TABLE VII

Regression equations and coefficients of multiple determination

Number of predictors	Regression Equation	R^2
7a	$Y = 1.064406185 - .001422706874\ x_2 - .001806792687\ x_{10} + .001602167493\ x_9 + .0004221720335\ x_8 + .0004902917198\ x_{11} - .001026742766\ x_4 + .0008985451087\ x_1$	.4154
6a	$Y = 1.066981074 - .001379703864\ x_2 - .001951859064\ x_{10} + .001419310161\ x_9 + .0006185512495\ x_8 + .0005064307596\ x_{11} - .0006640709539\ x_4$	.4123
5a	$Y = 1.066717096 - .001472767431\ x_2 - .0002130146999\ x_{10} + .001282782162\ x_9 + .0007669207101\ x_8 + .0002824216861\ x_{11}$	.4069
4a	$Y = 1.067151712 - .001343306946\ x_2 - .001840683008\ x_{10} + .00179616506\ x_9 + .0007686743986\ x_8$	.3943
4b	$Y = 1.067898738 - .0009287620767\ x_2 - .001641948653\ x_{10} + .0005807588240\ x_8 + .0001620458049\ x_{11}$	.3398
4c	$Y = 1.068209367 - .001305197050\ x_2 - .001428058454\ x_{10} + .001061269665\ x_9 + .0002848564914\ x_{11}$	.3592
3a	$Y = 1.068651181 - .001174231401\ x_2 - .001134473874\ x_{10} + .000956701648\ x_9$	.3463

TABLE VII(continued)

Number of predictors	Regression Equation	R^2
3b	$Y = 1.068100498 - .008778385911\ x_2 - .001493294270\ x_{10} + .0005906960649\ x_8$	.3355
3c	$Y = 1.068916938 - .008705649294\ x_2 - .001153656267\ x_{10} + .0001803998467\ x_{11}$	.3113
2a	$Y = 1.069161420 - .0008126527951\ x_2 - .0009785238008\ x_{10}$	.3059
2b	$Y = 1.066175371 - .001557690844\ x_2 + .0006681455788\ x_9$	.2576
2c	$Y = 1.067107527 - .001215417226\ x_2 - .00008003953384\ x_8$	.2380
2d	$Y = 1.067409618 - .001129594866x_2 - .0001659584845\ x_{11}$	.2435
2e	$Y = 1.061042093 - .001586586274\ x_{10} + .0001678881575\ x_9$	.2381
2f	$Y = 1.060386897 - .001963408414\ x_{10} + .0004724139528\ x_8$	.2557
1a	$Y = 1.066795095 - .001255841509\ x_2$	.2371
1b	$Y = 1.061713193 - .001517162133\ x_{10}$	.2364
1c	$Y = 1.060978279 - .001455021044\ x_4$	.1822

x_1 = chin
x_2 = tricep
x_4 = iliac
x_8 = waist
x_9 = patella
x_{10} = umbilical
x_{11} = abdominal

TABLE VIII

Estimates of specific gravity obtained from the regression equations developed in this study

Equation	Mean	Standard Deviation	Range	R
7a	1.0475	± .0069	1.0318 - 1.0608	.6445
6a	1.0475	± .0069	1.0312 - 1.0608	.6376
5a	1.0475	± .0068	1.0315 - 1.0594	.6376
4a	1.0475	± .0067	1.0300 - 1.0582	.6270
4b	1.0475	± .0067	1.0300 - 1.0582	.5829
4c	1.0475	± .0064	1.0324 - 1.0586	.5996
3a	1.0475	± .0063	1.0310 - 1.0597	.5883
3b	1.0475	± .0062	1.0351 - 1.0586	.5800
3c	1.0475	± .0060	1.0590 - 1.0366	.5579
2a	1.0475	± .0059	1.0354 - 1.0597	.5521
2b	1.0475	± .0054	1.0357 - 1.0581	.5078
2c	1.0475	± .0052	1.0379 - 1.0585	.4861
2d	1.0475	± .0053	1.0373 - 1.0591	.4936
2e	1.0475	± .0052	1.0337 - 1.0553	.4883
2f	1.0475	± .0054	1.0345 - 1.0545	.5063
1a	1.0475	± .0052	1.0375 - 1.0583	.4865
1b	1.0475	± .0052	1.0346 - 1.0556	.4862
1c	1.0475	± .0035	1.0377 - 1.0560	.4287

which predicted forty-one percent of the variation in the specific gravity. Equation 5a included the triceps, umbilical, patella, waist, and abdominal skinfold sites. In many testing situations, the abdominal skinfold site may be inaccessible and difficult to locate precisely. By dropping the abdominal skinfold site (equation 4a), the predictive power of the regression equation is lowered by only two percent; thirty-nine percent of the measured specific gravity is still predictable. Deletion of more skinfold sites from the equation causes a rapid loss of predictive power. The best three-predictor equation (3a) has a coefficient of multiple determination of 0.35, the best two predictor equation (2a) has a coefficient of 0.31, and the two one-predictor equations (using the triceps and umbilical sites, respectively) each have a coefficient of 0.24.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The dual purpose of this study was to investigate the accuracy with which the skinfold regression formulae developed by Young et al (70) would predict the specific gravity of a group of physical education students, and to develop other regression equations which might be more applicable to physically active individuals.

Twenty-four randomly selected female physical education students from the University of Alberta participated in the study. The specific gravity of the subjects was estimated using a Harpenden skinfold caliper. The measurements were obtained by following the techniques outlined by Brozek (16). The skinfold sites were those described by Young et al (70).

The difference between the thicknesses of the skinfolds, taken from the same site but from opposite sides of the body, was tested for significance using a correlated t test as described by Ferguson (36). The skinfold measures from the right side of the body were substituted into the regression formulae given by Young et al (70), and multiple correlation coefficients between the predicted and measured specific gravity values were tested for significance according to Ferguson (36).

Multiple regression equations were also derived from the data according to the method outlined by Guilford (42). The multiple correlation coefficients were tested for significance (36) and the differences between the coefficients were tested for significance (42).

The measures of specific gravity and body density, obtained by the hydrostatic weighing technique, were used to test the degree of consensus between the three formulae for estimating body fat content (17,49,58). A one-way analysis of variance, as outlined by Edwards (31), was used for this purpose.

Conclusions

Within the limitations of this study, the following conclusions were made.

1. The skinfold regression formulae developed by Young et al (70) do not give an accurate estimate of the individual's specific gravity for physical education women. This is indicated by the non-significant coefficient of correlation, at the 0.05 level.

2. No significant difference, at the 0.05 level, was found to exist between the skinfolds of the right and left sides of the body, except at the triceps and xyphoid sites.

3. A significant difference was found, at the 0.05 level, between the estimates of percent body fat obtained from the three formula.

4. The combination of the triceps, umbilical, patella, and waist skinfold sites according to equation 4a was the best predictor of specific gravity when both the accessibility of the sites and the predictive power of the equation were considered.

Recommendations

1. That the skinfold regression formulae developed by Sloan, Burt, and Blyth (62), by Durnin and Rahaman (30), and by Katch and Michael (47) be tested on a group of physically active young women.

2. That the proportion of subcutaneous fat to total body fat be examined, in group of women of various activity levels, to determine whether the proportional relationship is altered by physical activity.

3. That the subcutaneous fat pattern be examined in physically active young women and in international calibre athletes to determine whether the pattern is altered by physical activity.

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APPENDICES

APPENDIX A

STATISTICAL PROCEDURES AND SAMPLE CALCULATION SHEETS

Estimating Missing Values

Several skinfolds were not obtained, but were estimated by the repeated application of the formula described by Goulden (41:318):

$$x_{ij} = \frac{c\,C_j + r\,R_i - G}{(c-1)\,(r-1)}$$

where x_{ij} = the missing value in replication i and treatment j

c = the number of treatments

C_j = the sum of treatment j

r = the number of replications

R_i = the sum of replication i

G = the sum of the matrix

If there is more than one missing value, the mean of the matrix is substituted for all but one of the missing values. The sum of the matrix is given as:

G = the sum of the matrix + ((the number of missing values - 1) x the mean of the matrix). (41:320)

The estimated values of the missing observations are added to the sum of the appropriate row or column, and the approximation of each missing value is repeated until the same value is obtained on two successive repetitions (41:322).

The Difference Between Two Means for Correlated Samples

The difference between the skinfold measurements taken on the right and left sides of the body was tested for significance using the correlated t test (35:170).

$$t = \frac{\Sigma D}{\sqrt{[N\Sigma D^2 - (\Sigma D)^2]/(N-1)}}$$

where D = the difference between the right and left measurements

N = the number of observations.

Correlation Coefficients

Correlation coefficients of specific gravity to the skinfold thicknesses, and of specific gravity to regression equation estimates were calculated using the IBM 360/67 APL programme CM. This programme computes a matrix of simple correlation coefficients using the Pearson product - moment correlation (35:111).

$$r = \frac{N\Sigma xy - \Sigma x\ \Sigma y}{\sqrt{[N\Sigma x^2 - (\Sigma x)^2][N\Sigma y^2 - (\Sigma y)^2]}}$$

where r = the simple correlation coefficient between x and y

x = the sum of the X values

y = the sum of the Y values

N = the number of observations.

Multiple Regression Equations and Multiple Correlation Coefficients

Multiple regression equations were calculated to predict the specific gravity from various combinations of skinfolds. The estimates obtained were correlated with the measured specific gravity, yielding multiple correlation coefficients. The calculations were made using the IBM System 360/67 APL programme Streg.

The multiple regression equation has the general form (42:394):

$$x_1' = a + b_{12.3}\, x_2 + b_{13.2}\, x_3$$

where x_1' = the value predicted from a combination of x_2 and x_3

a = the constant calculated from the data

b = the multiplying constant for the x values.

$$b_{12.3} = \left(\frac{\sigma_1}{\sigma_2}\right)\left(\frac{r_{12} - r_{13}r_{23}}{1 - r_{23}}\right)$$

$$b_{13.2} = \left(\frac{\sigma_1}{\sigma_3}\right)\left(\frac{r_{13} - r_{12}r_{23}}{1 - r_{23}}\right)$$

where σ_1 = the standard deviation of x_1

r_{12} = the simple correlation coefficient between x_1 and x_2.

$$a = M_1 - b_{12.3}\, M_2 - b_{13.2}\, M_3$$

where M_1 = the mean of x_1 .

Significance of the Multiple Correlation Coefficient

The multiple correlation coefficients were tested for significance using (35:401):

$$F = \frac{R^2}{1 - R^2} \times \frac{N - k - 1}{k}$$

where R = the multiple correlation coefficient

N = the number of observations

k = the number of independent variables or predictors.

$$df_1 = k$$

$$df_2 = N - k - 1$$

Significant Difference Between Multiple Correlation Coefficients

In an attempt to derive short forms of the regression equation, each regression that showed a significant correlation was tested against the significant regression equation with the most predictors. The formula for the calculation was (42:400):

$$F = \frac{(R_1^{\,2} - R_2^{\,2})(N - m_1 - 1)}{(1 - R_1^{\,2})(m_1 - m_2)}$$

where R_1 = the multiple correlation with the larger number of independent variables

R_2 = the multiple correlation with one or more variables omitted

m_1 = the larger number of independent variables

m_2 = the smaller number of independent variables

N = the number of observations.

Coefficient of Multiple Determination

The coefficient of multiple determination or R^2 gives the proportion of variance in the dependent variable which is predicted by the multiple regression equation (42:397).

Analysis of Variance

A one-way analysis of variance (31:117) was used to test the difference between the estimates of percentage body fat obtained from the three formulae. The specific gravity values and the values predicted from Young's regression equation (70), and from the calculated regression equations, were tested using a one-way analysis of variance. The calculations were made using the IBM System 360/67 APL programme Anova 2.

Dunnett's Multiple Comparison

The specific gravity predictions from the skinfold measurements were tested for significant difference from the criterion specific

gravity using Dunnett's multiple comparison in which the control mean is compared to each treatment mean. The difference is significant if (31:150):

$$t = \frac{(\bar{x}_k - \bar{x}_o)}{\sqrt{2s^2/n}} \geq \text{critical } t_{k,(n-1) + k(n-1)}$$

where $\bar{x}_k$ = the mean of any given treatment group

$\bar{x}_o$ = the mean of the control group

s = the error mean square of the analysis of variance

n = the number of observations

k = the number of treatment groups

ESTIMATION OF BODY COMPOSITION

MEASUREMENTS	POUNDS	LITRES	CUBIC INCHES
Wt. in air	_____		
Vital Capacity (VC)		_____	_____
Residual Volume (RV)		_____	_____
Volume Gastro-Intestinal (VGI)			_____
Wt. in water (full inspiration	_____		

CALCULATIONS

Total lung capacity (TLC) = _____ (VC) + _____ (RV) + _____ (VGI)

= _____ TLC cu. in.

_____ TLC cu. in. x 0.0362 = _____ TLC lbs.

True Wt. = _____ (Wt. in water) + _____ (TLC lbs.) = _____

Body Volume = _____ (Wt. in air) - _____ (True Wt.)

Body Density = _____ (Wt. in air)/(_____ (Body Volume) x _____ (H_2O Density)

= _____

Specific Gravity = _____ (Body Density)/ _____ (H_2O Density) = _____

Rathbun Pace (1945) % fat = (5.548/Specific Gravity) - 5.044 = _____ %

Lbs. Fat = _____ (% Fat) x _____ (Wt.) = _____ lbs.

Lbs. Fat Free = _____ (Wt.) - _____ (lbs. Fat) = _____ lbs.

Keys-Brozek (1953) % Fat = (4.201/Body Density) - 3.813 = _____ %

Brozek et al (1963) % Fat = (4.570/Body Density) - 4.142 = _____ %

SKINFOLD MEASUREMENT

Site	Right				Left			
	1	2	3	Mean	1	2	3	Mean
Triceps								
Scapular								
Pectoralis								
Xyphoid								
Rib								
Waist								
Iliac								
Patella								
Umbilical								
Abdominal								
Chin								

REGRESSION EQUATIONS (Young 1962)

Specific gravity = Y2B = 1.0648 - .0003444 Abdominal

- .0001557 Rib - .0002803 Iliac

- .0006181 Chin + .0005768 Pectoralis

- .0004001 Patella

Specific gravity = Y3 = 1.0610 - .003164 Adbominal - .0003331 Rib

- .00005683 Tricep - .0002325 Iliac

Specific gravity = Y4 = 1.0615 - .0003910 Abdominal - .0005549 Rib

- .00007746 Tricep

Specific gravity = Y5B= 1.0607 - .0004193 Abdominal - .0005804 Rib

Specific gravity = Y6 = 1.0604 - .0005935 Abdominal

APPENDIX B

CORRELATION MATRICES

Correlation Matrix of Skinfold Measures to the Specific Gravity

Estimate from Hydrostatic Weighing

	Chin	Tricep	Scapular	Pectoralis	Xyphoid	Rib	Waist	Iliac	Patella	Umbilical	Abdominal	Sum
Tricep	.54											
Scapular	.62	.69										
Pectoralis	.73	.56	.74									
Xyphoid	.87	.52	.76	.89								
Rib	.97	.57	.82	.89	.96							
Waist	.65	.46	.67	.65	.78	.77						
Iliac	.71	.66	.70	.68	.71	.72	.37					
Patella	.17	.63	.64	.33	.29	.44	.27	.56				
Umbilical	.58	.55	.69	.78	.79	.80	.72	.69	.48			
Abdominal	.77	.52	.56	.75	.78	.80	.52	.83	.30	.67		
Sum	.81	.75	.86	.87	.91	.94	.76	.84	.57	.86	.84	
Specific Gravity	-.31	-.49	-.33	-.39	-.36	-.35	-.25	-.43	-.20	-.49	-.32	-.43

The Correlation Coefficients of the Estimate of Specific Gravity Obtained from Hydrostatic Weighing and the Estimated Values of Specific Gravity Obtained from Young's Skinfold Regression Equations

	Y2B	Y3	Y4	Y5B	Y6
Y3	.53				
Y4	.62	.62			
Y5B	.55	.55	.98		
Y6	.54	.99	.64	.58	
Specific Gravity	.17	.33	.16	.07	.32

APPENDIX C

RAW SCORES

Densitometric Measurements

Subject	Body Wt. (Kg.)	Density of H_2O (gm/ml)	Body Density (gm/ml)	Specific Gravity
1	50.5681	.9960	1.0335	1.0376
2	53.4090	.9960	1.0472	1.0514
3	55.7954	.9965	1.0416	1.0452
4	62.7272	.9965	1.0561	1.0598
5	62.7272	.9965	1.0419	1.0455
6	58.5227	.9965	1.0376	1.0412
7	68.1818	.9965	1.0385	1.0421
8	58.1818	.9965	1.0337	1.0373
9	68.4090	.9957	1.0531	1.0576
10	53.0454	.9954	1.0317	1.0364
11	67.2727	.9954	1.0392	1.0440
12	58.8636	.9954	1.0544	1.0592
13	65.2272	.9954	1.0439	1.0487
14	52.1596	.9954	1.0502	1.0550
15	56.8181	.9951	1.0559	1.0610
16	48.7500	.9951	1.0340	1.0390
17	61.9318	.9951	1.0560	1.0611
18	61.7045	.9957	1.0471	1.0516
19	57.8409	.9951	1.0239	1.0289
20	64.7727	.9951	1.0209	1.0259
21	64.4318	.9951	1.0521	1.0572
22	62.3863	.9957	1.0504	1.0549
23	61.3636	.9951	1.0309	1.0359
24	49.6590	.9951	1.0566	1.0618

Skinfold Measurements on the Right
Hand Side of the Body (mm.)

Subject	Tricep	Scapular	Pectoralis	Xyphoid	Rib
1	15.0	11.8	4.1	7.6	9.9
2	9.1	6.9	3.0	6.4	6.6
3	15.0	9.8	2.8	8.1	9.2
4	17.1	12.2	4.4	8.2	10.5
5	12.9	9.7	3.2	4.7	5.5
6	10.9	8.6	2.3	7.0	7.8
7	21.8	17.3	5.8	9.7	14.8
8	15.8	14.6	3.9	7.0	10.0
9	17.7	12.1	4.4	8.5	12.3
10	14.2	10.4	3.1	7.3	8.5
11	13.1	9.1	3.3	5.5	6.2
12	11.6	11.0	5.1	9.0	13.7
13	16.5	13.9	4.3	9.0	12.8
14	12.3	6.2	0.3	4.0	5.4
15	15.1	9.8	3.2	5.3	6.1
16	15.5	8.0	2.3	5.5	6.2
17	15.8	10.1	3.4	5.4	6.3
18	20.5	15.1	4.7	9.4	10.9
19	23.3	11.1	4.0	6.4	8.9
20	20.0	15.4	10.4	14.2	19.1
21	13.2	8.3	2.7	6.5	6.9
22	13.3	11.1	5.0	9.0	10.9
23	22.8	9.5	4.9	7.9	10.3
24	6.8	5.2	1.9	3.6	3.7

Skinfold Measurements on the Right
Hand Side of the Body (mm.)

Subject	Waist	Iliac	Patella	Umbilical	Abdominal
1	13.0	10.2	6.5	15.0	17.5
2	9.7	6.7	6.3	11.0	11.9
3	8.7	10.0	4.9	6.7	15.2
4	14.9	10.1	9.2	11.0	17.6
5	8.0	7.5	7.5	5.6	8.7
6	6.2	12.6	6.6	7.6	16.6
7	11.1	14.5	17.0	13.7	18.3
8	10.7	9.2	9.2	8.1	13.3
9	15.6	12.8	10.2	11.8	19.5
10	17.2	5.6	6.5	9.6	8.1
11	8.7	6.7	7.1	9.4	10.5
12	14.7	9.6	8.3	9.2	26.2
13	21.0	7.3	11.5	12.6	12.0
14	7.7	5.4	4.3	4.9	12.2
15	6.5	6.6	8.0	5.3	9.0
16	9.6	6.5	5.8	5.4	14.0
17	6.5	9.1	7.7	6.9	15.3
18	18.5	10.9	7.3	10.6	18.8
19	11.5	14.5	14.0	12.4	22.8
20	19.7	16.0	6.4	17.9	31.9
21	10.7	9.5	7.7	8.5	13.6
22	14.1	9.0	5.8	8.6	17.8
23	11.7	9.1	7.6	9.5	15.3
24	4.2	3.4	3.7	4.2	3.7

Skinfold Measurements on the Left
Hand Side of the Body (mm.)

Subject	Tricep	Scapular	Pectoralis	Xyphoid	Rib
1	12.2	11.0	4.3	7.7	9.8
2	8.6	7.1	3.7	6.1	6.7
3	13.6	9.1	3.0	9.1	11.3
4	16.4	12.0	5.5	8.9	8.6
5	11.6	8.8	3.0	5.1	5.4
6	12.3	7.8	2.8	7.3	8.1
7	18.6	16.8	4.5	10.7	15.8
8	15.4	13.6	4.1	6.9	9.6
9	15.6	11.8	4.8	8.8	10.0
10	15.8	10.6	3.0	7.4	8.3
11	14.2	9.5	4.6	5.7	6.4
12	13.8	11.7	5.0	11.8	16.3
13	13.3	13.4	4.8	10.3	11.8
14	9.1	6.4	0.3	3.5	4.0
15	14.5	9.9	3.3	5.6	6.5
16	11.9	8.2	2.6	5.7	6.3
17	13.9	9.1	3.4	5.5	5.9
18	18.2	15.1	4.8	8.9	11.5
19	18.5	13.5	3.7	7.2	10.2
20	20.8	14.8	10.0	14.5	16.8
21	12.0	8.5	3.3	6.9	8.6
22	12.4	10.8	4.7	8.7	10.5
23	15.9	9.0	5.4	7.7	10.1
24	5.4	5.4	2.2	3.3	3.6

Skinfold Measurements on the Left
Hand Side of the Body (mm.)

Subject	Waist	Iliac	Patella	Umbilical	Abdominal
1	12.0	9.7	5.5	10.6	17.9
2	9.4	6.8	5.9	10.7	10.6
3	10.2	8.3	4.5	7.1	15.8
4	18.5	11.4	8.6	11.0	16.6
5	8.5	6.1	7.9	5.4	9.4
6	6.5	12.5	6.4	7.0	18.9
7	11.6	13.9	10.9	10.9	19.4
8	11.9	8.4	10.0	7.7	9.6
9	10.2	13.1	9.1	11.4	20.5
10	14.8	5.9	5.5	9.5	8.3
11	9.1	7.2	5.9	7.5	11.6
12	20.9	8.4	8.2	9.5	13.9
13	19.9	7.5	11.5	11.1	11.5
14	8.7	6.0	3.8	4.5	12.5
15	5.8	6.4	7.7	5.5	9.0
16	6.5	5.6	5.4	7.0	14.4
17	7.5	8.4	6.0	6.7	16.1
18	18.3	12.4	7.3	11.6	18.6
19	12.0	14.4	15.6	12.8	24.6
20	17.8	16.5	6.3	19.0	32.3
21	8.1	8.7	8.7	8.3	13.8
22	11.6	8.6	6.0	8.7	16.5
23	16.7	7.4	8.3	8.7	15.3
24	4.1	3.1	4.1	4.2	3.9

Chin and Sums of Skinfold Measurements (mm.)

Subject	Chin	Right Sum	Left Sum	Total	Total 2 (Right sum plus chin)
1	6.6	110.6	100.7	217.9	117.2
2	5.6	77.6	75.6	158.8	83.2
3	9.1	90.3	92.0	191.4	99.4
4	6.9	115.2	117.5	249.1	122.1
5	5.6	73.3	71.2	150.1	78.9
6	7.7	86.2	89.6	183.1	93.9
7	7.2	144.0	133.1	284.3	151.2
8	5.9	101.8	97.2	204.9	107.7
9	7.6	124.9	115.3	247.8	132.5
10	6.7	90.5	89.1	186.3	97.2
11	5.1	79.6	81.7	166.4	84.7
12	7.8	118.4	119.5	245.7	126.2
13	8.2	120.9	115.1	244.2	129.1
14	5.5	62.7	58.8	127.0	68.2
15	6.9	74.9	74.2	156.0	81.8
16	6.1	78.8	73.6	158.5	84.9
17	6.7	86.5	82.5	175.7	93.2
18	9.3	126.7	126.7	262.7	136.0
19	7.6	128.9	132.5	269.0	136.5
20	11.6	171.0	168.8	351.4	182.6
21	6.6	87.6	86.9	181.1	94.2
22	8.2	104.6	98.5	211.3	112.8
23	7.1	108.6	104.5	220.2	115.7
24	3.8	40.4	39.3	83.5	44.2

Body Fat Estimated from the Rathbun-Pace (1945),

Keys and Brozek (1953), and Brozek et al (1963) Formula

Subject	Percentage Fat			Kg. Fat		
	Rathbun Pace	Keys Brozek	Brozek et al	Rathbun Pace	Keys Brozek	Brozek et al
1	30.2954	25.1828	27.9948	15.3198	12.7345	14.1564
2	23.2773	19.8650	22.2094	12.4322	10.6097	11.8618
3	25.9001	22.0218	24.5638	14.4511	12.2872	13.7055
4	19.0950	16.4843	18.5178	11.9778	10.3401	11.6157
5	26.2552	21.9057	24.4370	16.4691	13.7408	15.3286
6	28.4467	23.5766	26.2300	16.4678	13.7977	15.3505
7	27.9865	23.2258	25.8479	19.0817	15.8357	17.6235
8	30.4501	25.1048	27.8966	17.7164	14.6061	16.2307
9	20.1839	17.6175	19.7546	13.8076	12.0519	13.5139
10	30.9146	25.8920	28.7721	16.3987	13.7345	15.2623
11	27.0176	22.9533	25.5428	18.1755	15.4413	17.1823
12	19.3915	17.1256	19.2339	11.4146	10.0808	11.3217
13	24.6359	21.1332	23.5886	16.0693	13.7846	15.3861
14	21.4768	18.7190	20.9471	11.2022	9.7638	10.9258
15	18.5029	16.5596	18.6123	10.5130	9.4089	10.5751
16	29.5749	24.9863	27.7918	14.4178	12.1808	13.5800
17	18.4536	16.5220	18.5477	11.4286	10.2324	11.4869
18	23.1770	19.9033	22.2397	14.3013	12.2812	13.7229
19	34.8166	28.9940	32.1426	20.1383	16.7704	18.5915
20	36.3934	30.1997	33.4490	23.5730	19.5611	21.6658
21	20.3824	17.9966	20.1842	13.1328	11.5956	13.0050
22	21.5266	18.6429	20.8838	13.4297	11.6306	13.0286
23	31.1729	26.2080	29.1102	19.1288	16.0822	17.0286
24	18.1089	16.2961	18.3034	8.9927	8.0925	17.8630

Specific Gravity Estimated from

Young's Regression Equations

Subject	Y2B	Y3	Y4	Y5B	Y6
1	1.0612	1.0008	1.0590	1.0591	1.0500
2	1.0624	1.0201	1.0598	1.0595	1.0533
3	1.0634	1.0084	1.0594	1.0597	1.0514
4	1.0606	1.0004	1.0591	1.0594	1.0500
5	1.0628	1.0306	1.0602	1.0602	1.0552
6	1.0601	1.0036	1.0585	1.0583	1.0505
7	1.0576	0.9960	1.0609	1.0616	1.0495
8	1.0613	1.0143	1.0606	1.0609	1.0525
9	1.0595	0.9932	1.0593	1.0597	1.0488
10	1.0650	1.0320	1.0619	1.0622	1.0556
11	1.0624	1.0249	1.0598	1.0599	1.0542
12	1.0596	0.9720	1.0579	1.0577	1.0449
13	1.0635	1.0180	1.0626	1.0631	1.0533
14	1.0617	1.0200	1.0588	1.0587	1.0532
15	1.0636	1.0298	1.0602	1.0605	1.0551
16	1.0618	1.0140	1.0583	1.0584	1.0521
17	1.0609	1.0093	1.0578	1.0579	1.0513
18	1.0624	0.9965	1.0586	1.0591	1.0492
19	1.0556	0.9838	1.0557	1.0563	1.0469
20	1.0628	0.9511	1.0581	1.0584	1.0415
21	1.0610	1.0142	1.0590	1.0590	1.0523
22	1.0634	0.9997	1.0596	1.0596	1.0498
23	1.0627	1.0083	1.0595	1.0603	1.0513
24	1.0650	1.0477	1.0616	1.0613	1.0582

Specific Gravity Estimates

From the Present Study

Subject	7A	6A	5A	4A	4B	4C
1	1.0359	1.0364	1.0359	1.0371	1.0397	1.0391
2	1.0498	1.0495	1.0488	1.0496	1.0489	1.0507
3	1.0478	1.0466	1.0476	1.0471	1.0505	1.0486
4	1.0457	1.0464	1.0463	1.0462	1.0455	1.0450
5	1.0529	1.0533	1.0540	1.0545	1.0528	1.0538
6	1.0505	1.0504	1.0524	1.0511	1.0516	1.0549
7	1.0411	1.0408	1.0409	1.0412	1.0346	1.0434
8	1.0489	1.0497	1.0500	1.0501	1.0483	1.0496
9	1.0441	1.0450	1.0461	1.0457	1.0443	1.0446
10	1.0488	1.0489	1.0492	1.0513	1.0502	1.0452
11	1.0467	1.0469	1.0461	1.0473	1.0471	1.0482
12	1.0608	1.0608	1.0594	1.0557	1.0548	1.0562
13	1.0512	1.0502	1.0498	1.0515	1.0460	1.0443
14	1.0536	1.0539	1.0530	1.0526	1.0549	1.0532
15	1.0527	1.0514	1.0510	1.0515	1.0504	1.0520
16	1.0516	1.0520	1.0511	1.0506	1.0525	1.0504
17	1.0487	1.0484	1.0479	1.0473	1.0481	1.0503
18	1.0420	1.0421	1.0428	1.0429	1.0452	1.0394
19	1.0393	1.0395	1.0392	1.0384	1.0363	1.0414
20	1.0318	1.0312	1.0315	1.0300	1.0365	1.0324
21	1.0500	1.0503	1.0511	1.0511	1.0501	1.0509
22	1.0520	1.0518	1.0521	1.0511	1.0525	1.0498
23	1.0365	1.0367	1.0359	1.0370	1.0404	1.0373
24	1.0569	1.0573	1.0572	1.0582	1.0581	1.0586

Specific Gravity Estimates

From the Present Study (Continued)

Subject	3A	3B	3C	2A	2B	2C
1	1.0402	1.0402	1.0417	1.0423	1.0472	1.0478
2	1.0515	1.0494	1.0505	1.0510	1.0562	1.0553
3	1.0481	1.0501	1.0509	1.0504	1.0461	1.0482
4	1.0449	1.0455	1.0445	1.0445	1.0457	1.0451
5	1.0543	1.0531	1.0528	1.0532	1.0511	1.0508
6	1.0535	1.0508	1.0537	1.0529	1.0536	1.0534
7	1.0438	1.0351	1.0374	1.0380	1.0436	1.0397
8	1.0497	1.0485	1.0482	1.0484	1.0477	1.0470
9	1.0442	1.0442	1.0434	1.0432	1.0458	1.0443
10	1.0473	1.0515	1.0469	1.0482	1.0484	1.0485
11	1.0494	1.0477	1.0486	1.0493	1.0505	1.0505
12	1.0525	1.0529	1.0529	1.0507	1.0537	1.0518
13	1.0460	1.0472	1.0422	1.0434	1.0482	1.0454
14	1.0528	1.0545	1.0548	1.0544	1.0499	1.0515
15	1.0526	1.0508	1.0513	1.0517	1.0480	1.0482
16	1.0499	1.0521	1.0517	1.0513	1.0459	1.0475
17	1.0496	1.0478	1.0500	1.0496	1.0467	1.0474
18	1.0395	1.0452	1.0422	1.0421	1.0391	1.0407
19	1.0406	1.0359	1.0384	1.0381	1.0392	1.0379
20	1.0310	1.0355	1.0366	1.0354	1.0393	1.0412
21	1.0509	1.0501	1.0501	1.0501	1.0508	1.0502
22	1.0488	1.0519	1.0506	1.0499	1.0493	1.0498
23	1.0384	1.0408	1.0409	1.0413	1.0357	1.0385
24	1.0597	1.0586	1.0590	1.0597	1.0581	1.0585

Specific Gravity Estimates

From the Present Study (continued)

Subject	2D	2E	2F	2G	1A	1B	1C
1	1.0476	1.0383	1.0371	1.0389	1.0480	1.0390	1.0461
2	1.0552	1.0446	1.0434	1.0450	1.0554	1.0450	1.0512
3	1.0479	1.0512	1.0513	1.0516	1.0480	1.0515	1.0464
4	1.0452	1.0451	1.0458	1.0450	1.0453	1.0450	1.0463
5	1.0514	1.0534	1.0532	1.0532	1.0506	1.0532	1.0501
6	1.0523	1.0501	1.0484	1.0502	1.0531	1.0502	1.0426
7	1.0397	1.0422	1.0387	1.0409	1.0394	1.0409	1.0399
8	1.0474	1.0497	1.0495	1.0494	1.0470	1.0494	1.0476
9	1.0442	1.0440	1.0446	1.0438	1.0446	1.0438	1.0424
10	1.0500	1.0469	1.0497	1.0471	1.0490	1.0471	1.0528
11	1.0509	1.0473	1.0460	1.0474	1.0503	1.0475	1.0512
12	1.0500	1.0478	1.0493	1.0479	1.0522	1.0478	1.0470
13	1.0468	1.0430	1.0456	1.0425	1.0461	1.0426	1.0504
14	1.0515	1.0540	1.0544	1.0543	1.0513	1.0543	1.0531
15	1.0489	1.0540	1.0531	1.0537	1.0478	1.0537	1.0514
16	1.0476	1.0534	1.0543	1.0536	1.0473	1.0535	1.0515
17	1.0470	1.0514	1.0499	1.0513	1.0470	1.0512	1.0477
18	1.0411	1.0454	1.0483	1.0457	1.0411	1.0456	1.0451
19	1.0373	1.0437	1.0415	1.0429	1.0375	1.0429	1.0399
20	1.0395	1.0337	1.0345	1.0346	1.0417	1.0346	1.0377
21	1.0502	1.0488	1.0488	1.0488	1.0502	1.0488	1.0472
22	1.0494	1.0484	1.0502	1.0487	1.0501	1.0487	1.0479
23	1.0391	1.0472	1.0473	1.0473	1.0382	1.0473	1.0477
24	1.0591	1.0553	1.0545	1.0556	1.0583	1.0556	1.0560